# TennisSense Demonstrator Rev 1.0
# Hardware Manual

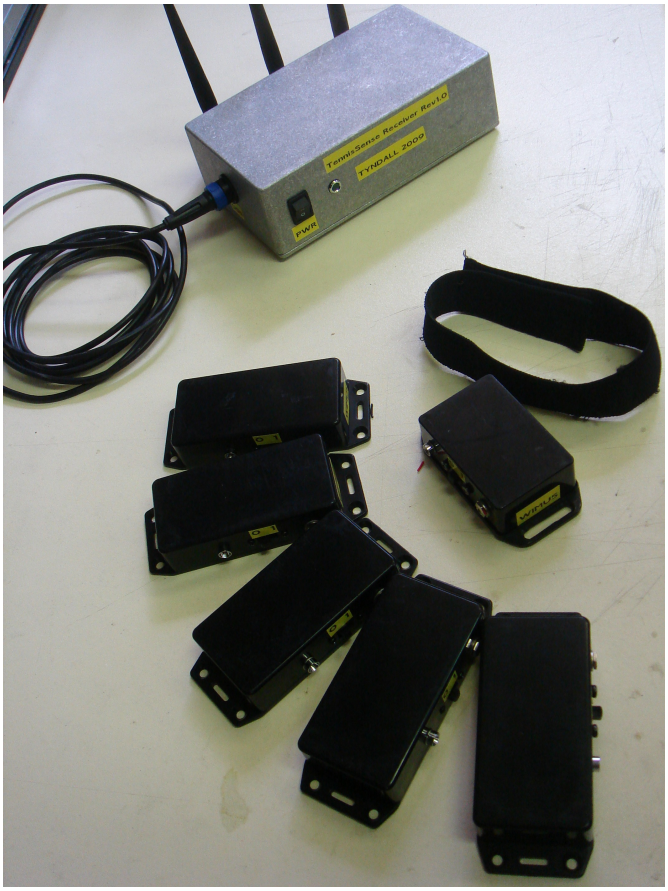


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**Table of Contents**

1 Introduction....4
2 WIMU Hardware....5
2.1 IMU Layer....5
2.2 Nordic Radio/ATmega128 Layer....6
2.3 NAP150 Board....7
2.4 Battery....7
2.5 Packaging....8
3 WIMU Specification....9
3.1 Physical Specifications overview....9
3.1.1 WIMU....9
3.1.2 Charger....9
3.1.3 Charger Connector....10
3.2 Cable and connector....11
3.3 Housing....12
3.3.1 WIMU....12
3.3.2 Radio Receiver....13
4 Labview GUI....14
4.1 WIMU binary output format....14
4.2 Reading IMU samples from Receiver....14
4.3 Labview GUI Description....16
5 Important notices....18
5.1 Environmental Operating Conditions....18
6 References & Datasheets....19
7 Quick Start Guide....20

# 1 Introduction

The TennisSense system consists of up to 6 wearable Wireless Inertial Measurement Units (WIMUs) worn by a tennis player, a wireless receiver (Rx) and a connected PC as illustrated in figure 1 below. This system allows for the measurement and recording of the instrumented player's kinematic motion data.

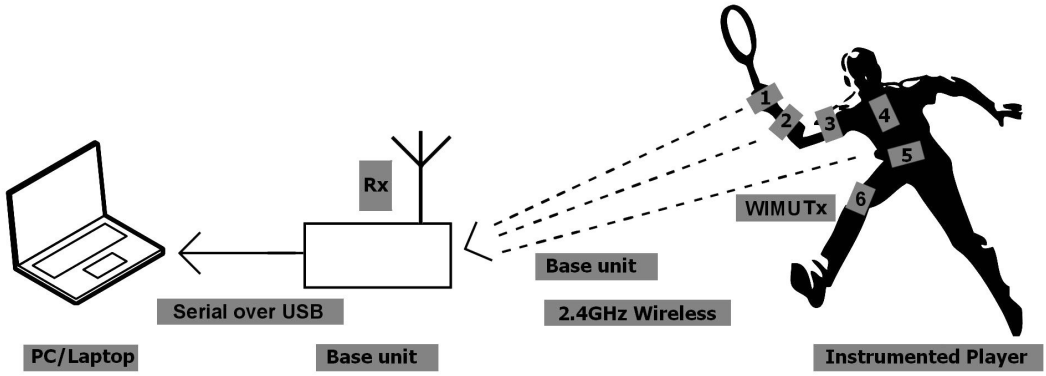



**Figure 1: TennisSense WIMU system overview**

In operation, when a player is serving for instance, the body-worn WIMUs monitor the movement of the player's arm (upper, lower and wrist) as well as the chest and torso. The sensor data are then transmitted wirelessly in real-time to the receiver (Base unit), which is linked to a PC via a USB cable. The receiver features a serial over USB chip which allows the device to appear as a virtual COM port, allowing the data to be easily accessed for display on the included Labview program.

# 2 WIMU Hardware

The assembled hardware of the WIMU is composed of a NAP150 Board (power supply, battery management and integral dual-axis 70g/37g accelerometer), an IMU layer (9x motion sensors), a 1Mbps Nordic Radio with ATmega128 layer (wireless communication and processing) and a prismatic lithium polymer battery (1230mAh).

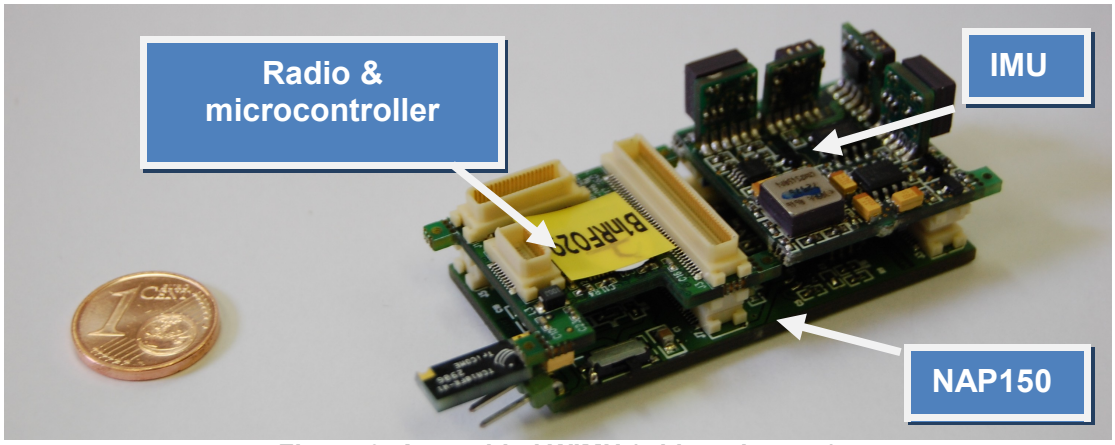



**Figure 2: Assembled WIMU (without battery)**

## 2.1 IMU Layer

The Inertial Measurement Unit (IMU) layer contains multiple accelerometers, gyroscope and magnetometer sensors arranged so that their axes of sensitivity form orthogonal triplets. This allows for the monitoring of 6 degrees of freedom motion data for each WIMU.

The IMU is shown in Figure 3 and features 3x single-axis gyroscopes, 2x dual-axis accelerometers, 2x dual-axis magnetometers, a 12-bit ADC as well as signal conditioning circuitry.

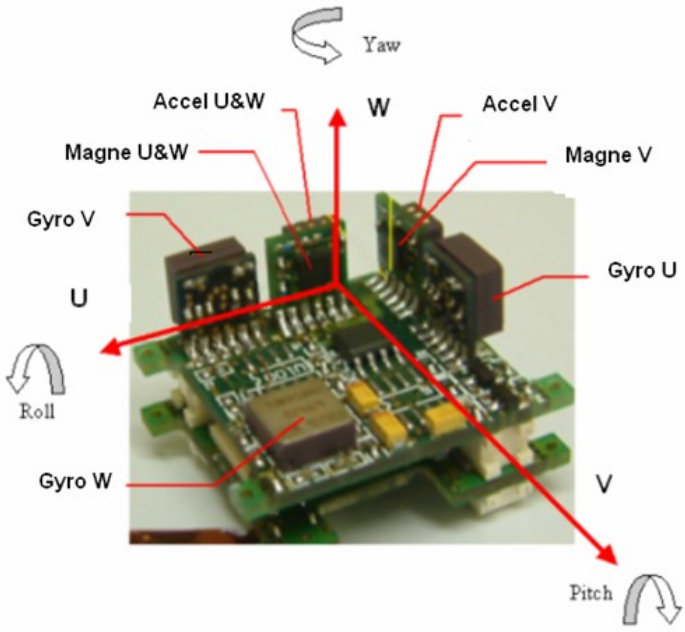



**Figure 3: Details of sensors and axes of sensitivity for the IMU layer**

### Physical sensor specification

The key technical specification for the gyroscopes, the accelerometers and the magnetometers used in each IMU layer are listed in Table 1. Please refer to the individual datasheets (See “References” at the end of the manual) for further specifications.

| | Accelerometer | Gyroscope | Magnetometer |
|---|---|---|---|
| **Number of axis** | 2 (x,y) | 1 (z) | 2 (x,y) |
| **Range** | ± 10g | Up to ± 1200˚/s | ± 6gauss |
| **Sensitivity** | 55mV/g | 6mV/˚/sec | 1mV/V/gauss |
| **Part number** | ADXL210 | ADXRS300 | HMC1052L |
| **Manufacturer** | Analog Devices | Analog Devices | Honeywell |

**Table 1: Sensors specifications**

## 2.2 Nordic Radio/ATmega128 Layer

The radio transceiver chosen for this application is the nRF2401 (see datasheet in “References”) from Nordic Semiconductor. The radio uses the 2.4GHz ISM band for communications with data transfer rates of up to 1Mbps.

The microcontroller is an ATmega128 (see datasheet in “References”) from Atmel. The microcontrollers have been tested, numbered and pre-programmed with the appropriate code for the TennisSense demonstrator.

The radio transceiver/microcontroller layer is shown in figure 4 with a chip antenna. They have also had the on board clock chip for the microcontroller replaced with a higher speed 16MHz unit for reduced latency in data transfer.

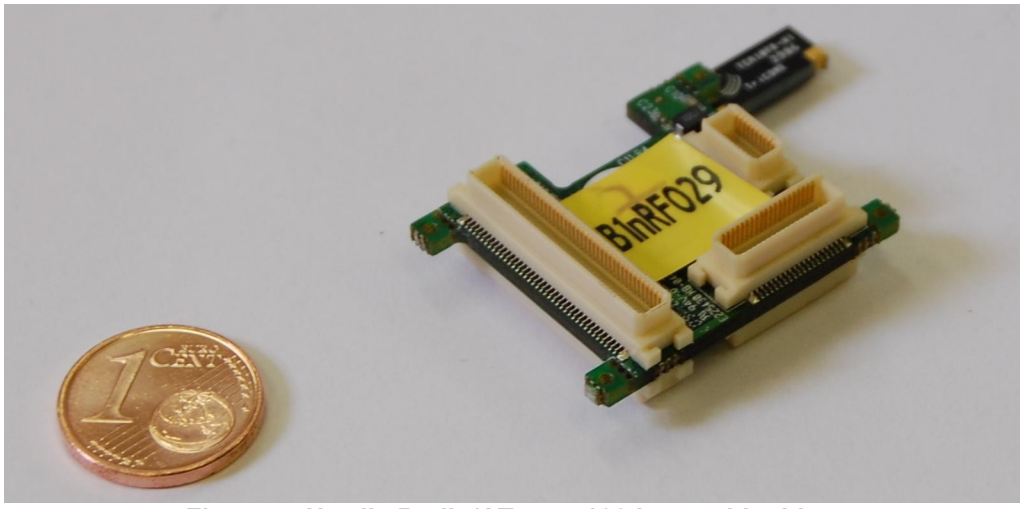



**Figure 4: Nordic Radio/ATmega128 layer with chip antenna**

## 2.3 NAP150 Board

The NAP150 board delivers a regulated 5V supply from the attached 3.7V lithium battery. It also features a supplemental 70g/37g dual-axis accelerometer, ADXL278 from Analog Devices (see datasheet in "References").

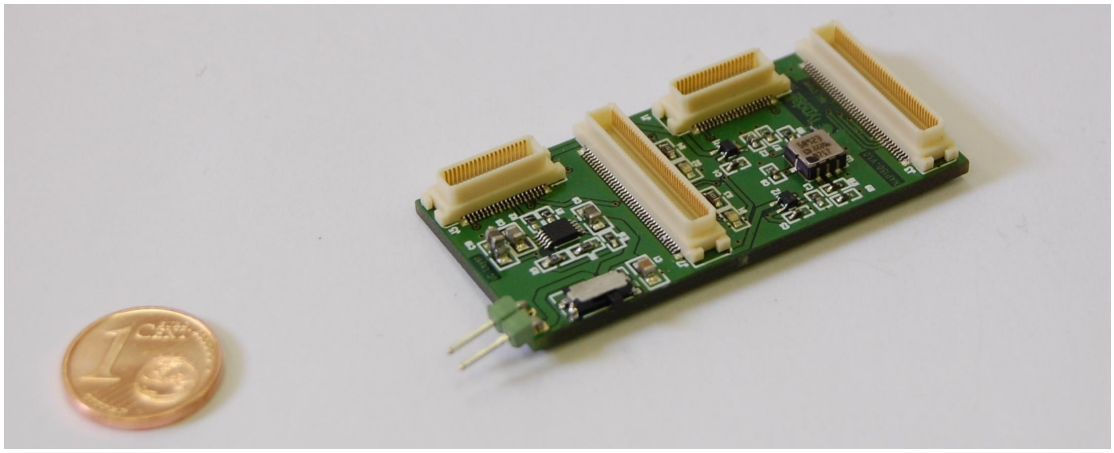


**Figure 5: NAP150 Board**

| | Accelerometer |
|---|---|
| **Number of axes** | 2 (x,y) |
| **Range** | ± 70g (x)<br>± 37g (y) |
| **Sensitivity** | 27mV/g (x)<br>55mV/g (y) |
| **Part number** | ADXL278 |
| **Manufacturer** | Analog Devices |

**Table 2: NAP150 Accelerometer Specifications**

## 2.4 Battery

The battery used is a 1230mAh LIP653450UC rechargeable Lithium Ion Prismatic cell from Varta (see datasheet in "References"). This should allow for several hours of operation before requiring recharging. The battery is glued in place to prevent it from impacting with the electronics and improve reliability.

**Figure 6: LIP653450UC Rechargeable Lithium Ion Prismatic Battery (recent versions have higher capacity than that illustrated)**

## 2.5 Packaging

The packaging is based around durable black ABS plastic enclosures. These have a main body with posts for receiving 4 screws and a flat base plate with four screw holes and “wings” to allow for securing the enclosures to other objects. The units should be kept screwed shut to keep out moisture and dirt which may cause premature failure. A small package of silica gel is also included in each WIMU to reduce the chance of moisture damaging the electronics. Aero-board is used to protect internal parts from damage due to physical shocks such as tennis ball impacts.

**Warning: Please do not disassemble without consulting with us first as parts are attached to both the main body and the flat base plate which are delicately connected.**

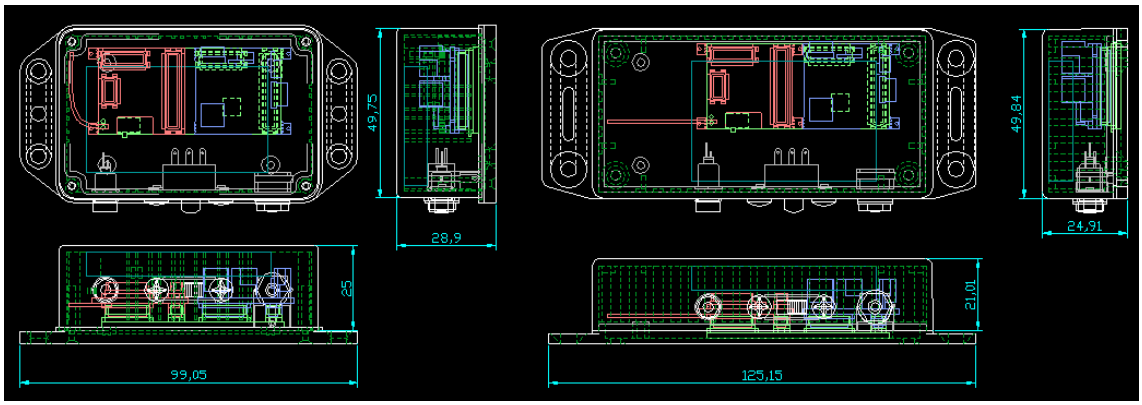



**Figure 7: Internal layout of parts for Tennis Sense WIMUs**

# 3 WIMU Specification

## 3.1 Physical Specifications overview

### 3.1.1 WIMU

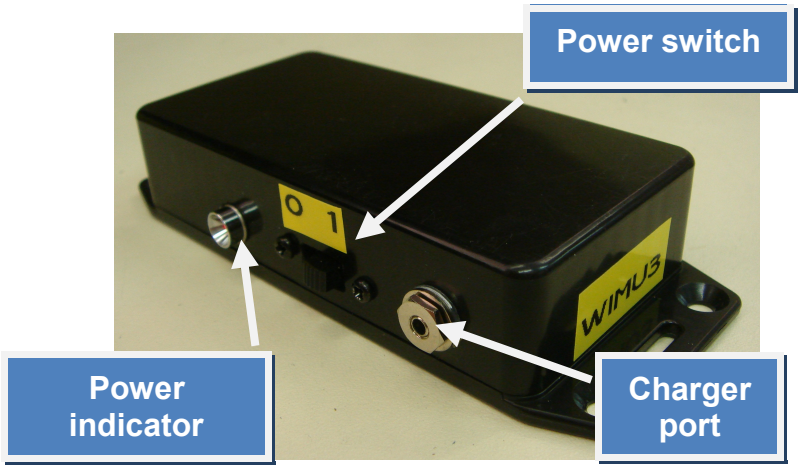



**Figure 8: WIMU in large enclosure**

**Warning: Please only use the supplied chargers to charge the WIMUs.**

### 3.1.2 Charger

The charger has a 2 colour status LED, this is red when a unit is being charged and changes to green once the attached WIMU is fully charged.

It is not necessary to turn the WIMUs on or off before charging. During charging the status LED and all electronics in the WIMU will be disconnected from power so they will not be functional.

**Figure 9: Charger with close up of connector**

### 3.1.3 Charger Connector

The charger connector used is a standard 2.5mm diameter 2 pole (mono) jack plug. The middle (tip) is positive, the outside (case) is at DC ground potential. The charger output voltage (no-load) is 4.2V DC.

**Warning: Ensure the polarity on all chargers used is correct before plugging into a WIMU. Use a voltmeter to verify charger voltage is 4.2V DC with polarity as shown.**

Table 3 shows the electrical and physical specifications for the WIMU and receiver units.

| | WIMU transmitter | Receiver |
|---|---|---|
| **Interface** | Wireless (Nordic) | USB (1Mbps serial over USB) |
| **Operating Voltage** | 4.2 V (from charger)<br>3.7 V (from battery)<br>5 V (from NAP150) | 5V |
| **Operating current** | 170mA DC | 120mA DC |
| **Temperature Operating Range** | 0 to 55 °C | 0 to 55 °C |
| **Outline Dimensions** | 125 x 50 x 25 mm (WIMU Large)<br>75 x 50 x 25 mm (WIMU Small) | 190 x 110 x 60 mm |
| **Weight** | 107g (WIMU Large)<br>91g (WIMU Small) | 672g |

**Table 3: Electrical and physical specification**

**Note: The expected time of play allowed by a fully charged battery is approximately 5-6h. The WIMU units need approximately 3h each to fully charge.**

## 3.2 Cable and connector

A USB cable is used to connect the receiver unit to the PC/laptop. The cable used is a standard USB to mini USB cable and employs a screw on connector to provide a robust connection and prevent it from being damaged or detached during play.

**Figure 10: Receiver unit connected to laptop**

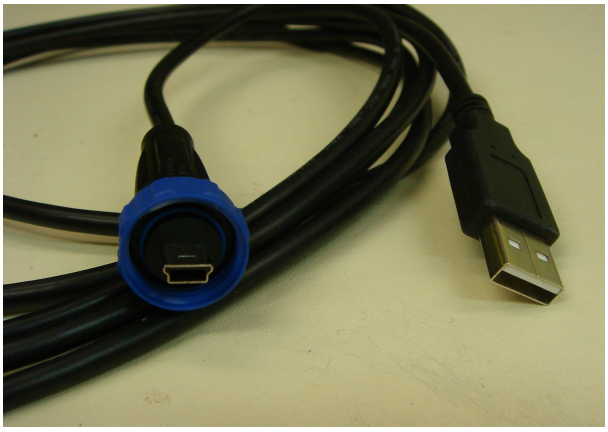


**Figure 11: Supplied USB cable**

## 3.3 Housing

### 3.3.1 WIMU

Two types of WIMU enclosures have been provided for evaluation: a large and small type. There are 5x WIMUs packaged in the large enclosure and 1x WIMU packaged in the small enclosure as can be seen in figure 12.

**Note: The small WIMU is a spare device that was used to evaluate a smaller, lighter implementation that would make it more comfortable on the wrist. However, the expected radio transmission range for the smaller unit is less than for the large WIMU device.**

**Figure 12: Set of 6x TennisSense WIMUs**

The large WIMUs have dimensions of 125 x 50 x 25 mm, with the smaller type having dimensions of 75 x 50 x 25 mm, any additional measurements required can be taken from the scaled drawing supplied. The axes of sensitivity are illustrated in figure 13.

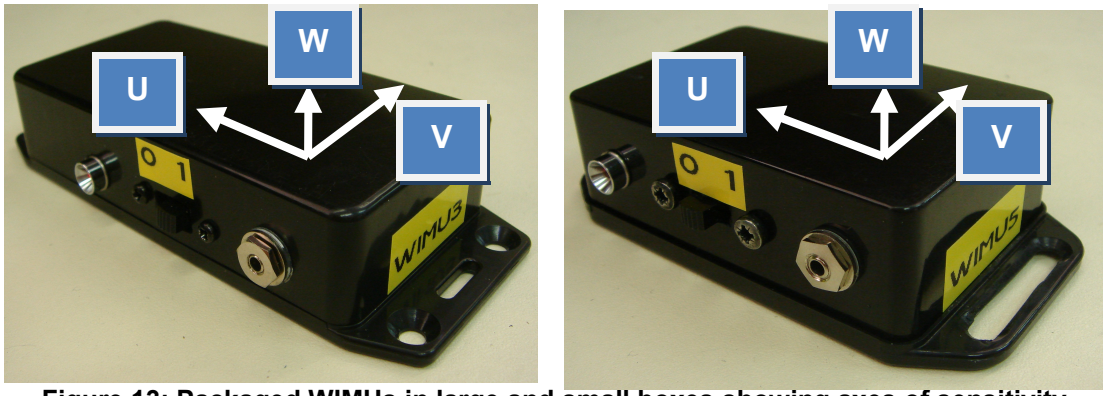



**Figure 13: Packaged WIMUs in large and small boxes showing axes of sensitivity**

### 3.3.2 Radio Receiver

The receiver unit is shown in figure 14. The receiver is used to receive wireless data from each of the 6 body-worn WIMU transmitters. It is connected to the (laptop/PC) via a USB cable as shown. The receiver collects data from the WIMU units and passes the received sensor data to the base station via RS-232 for display, logging and data analysis.

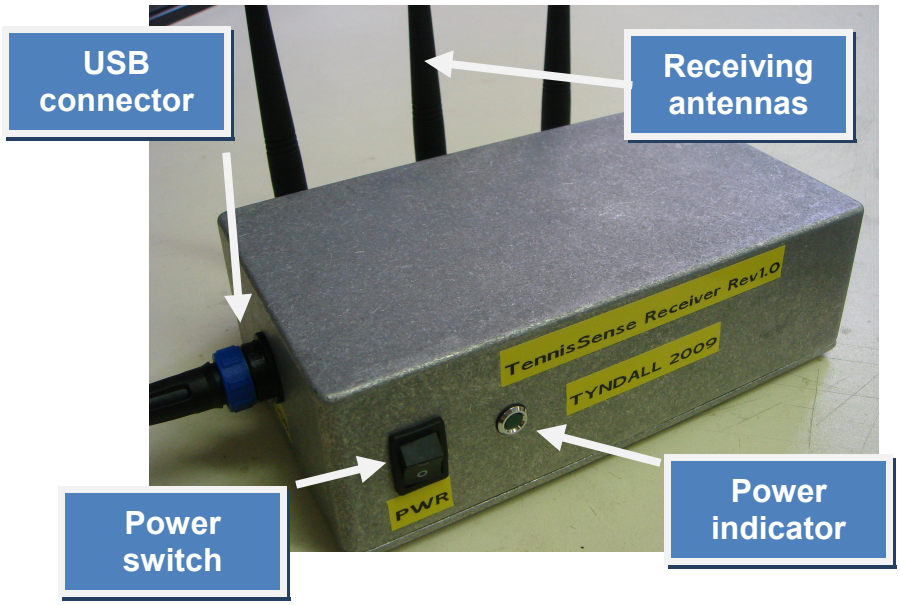



**Figure 14: TennisSense Radio Receiver unit**

# 4 Labview GUI

The supplied GUI software is written in Labview (National Instruments Version 8.2). Note that any computer program (e.g. C, C++ Visual-C, Visual Basic etc) that can access the data from the virtual COM port used by the receiver may be used to read the captured sensor data from the receiver.

Note that an *executable* GUI (i.e. Labview GUI) is also included such that it will run on any computer that does not have Labview installed. To run the executable, it is required to install the Labview8.2.1 and Visa430 runtimes which are both included on the CD.

Also note that to achieve the high data throughput required for this application, a serial baud rate of 1Mbps is required. The exact serial settings are listed in table 4.

## 4.1 WIMU binary output format

**Receiver Serial (over USB) Connection Settings**

| Settings | Value |
|---|---|
| **Bits/second (bps)** | 1M (1,000,000) |
| **Data bits** | 8 |
| **Parity** | None |
| **Stop bits** | 1 |
| **Flow control** | None |

**Table 4: Serial settings**

## 4.2 Reading IMU samples from Receiver

A very simple serial data format is employed for each sensor measurement and consists of:

- Start of measurement identifier ( in this case the string “imu”)
- WIMU number (1-6)
- 11 sensor readings
- Two termination characters

The exact measured data structure is listed in table 5. To read the measured ADC binary sensor data values from the COM port, simply wait for the start of measurement identifier (“imu”), then capture the WIMU number, and 11 sensor readings and then wait for the next start of measurement identifier.

| Byte | Description | Channel | ADC full scale Voltage | Comment |
|---|---|---|---|---|
| **1** | Character "i" | NA | NA | |
| **2** | Character "m" | NA | NA | |
| **3** | Character "u" | NA | NA | |
| **4** | WIMU number (1-6) | NA | NA | |
| **5** | Accel U (Hi Byte) | 0000XXXX | 5V | |
| **6** | Accel U (Lo Byte) | XXXXXXXX | 5V | |
| **7** | Accel V (Hi Byte) | 0000XXXX | 5V | |
| **8** | Accel V (Lo Byte) | XXXXXXXX | 5V | |
| **9** | Accel W (Hi Byte) | 0000XXXX | 5V | |
| **10** | Accel W (Lo Byte) | XXXXXXXX | 5V | |
| **11** | Gyro W (Hi Byte) | 0000XXXX | 5V | |
| **12** | Gyro W (Lo Byte) | XXXXXXXX | 5V | |
| **13** | Gyro U (Hi Byte) | 0000XXXX | 5V | |
| **14** | Gyro U (Lo Byte) | XXXXXXXX | 5V | |
| **15** | Gyro V (Hi Byte) | 0000XXXX | 5V | |
| **16** | Gyro V (Lo Byte) | XXXXXXXX | 5V | |
| **17** | Mag W (Hi Byte) | 0000XXXX | 5V | |
| **18** | Mag W (Lo Byte) | XXXXXXXX | 5V | |
| **19** | Mag U (Hi Byte) | 0000XXXX | 5V | |
| **20** | Mag U (Lo Byte) | XXXXXXXX | 5V | |
| **21** | Mag V (Hi Byte) | 0000XXXX | 5V | |
| **22** | Mag V (Lo Byte) | XXXXXXXX | 5V | |
| **23** | 70g Minus U (Hi Byte) | 0000 00XX | 3.3V | * |
| **24** | 70g Minus U (Lo Byte) | XXXX XXXX | 3.3V | * |
| **25** | 37g Plus V(Hi Byte) | 0000 00XX | 3.3V | * |
| **26** | 37g Plus V (Lo Byte) | XXXX XXXX | 3.3V | * |
| **27** | "New line" char | 0x0A | | |
| **28** | "Carriage Return" char | 0x0D | | |

***Note: The 70g/37g sensor readings are voltage divided. Please using scale factor of 1.555 to calculate true voltage**

The serial data format delivered from the receiver is implemented using the following embedded code:

```
void Serial_Data()

{
      printf("imu"); //This text indicates the start of a string of
IMU data
      putchar(data[0]); //Identify the data source (WIMU 1-6)

      for (i=0;i<9;i++)// 18 IMU layer bytes
      {
      putchar(data[2*i+1]&0x0F);//High byte of AD7490 ADC conversion
      putchar (data[2*i+1+1]);//Low byte of  AD7490 ADC conversion

      }
      for (i=9;i<11;i++)// 4 bytes of 70g/37g accelerometer
      {
      putchar(data[2*i+1]&0x03);//High byte of MCU ADC conversion
      putchar (data[2*i+1+1]);//Low byte of MCU ADC
      }

putchar(0x0A);
putchar(0x0D);
}
```

## 4.3 Labview GUI Description

The Labview GUI screen is shown in figure 15. It can be seen that each of the 11 sensor's outputs (gyroscopes, accelerometers and magnetometers) for a particular WIMU are graphed on screen at once.

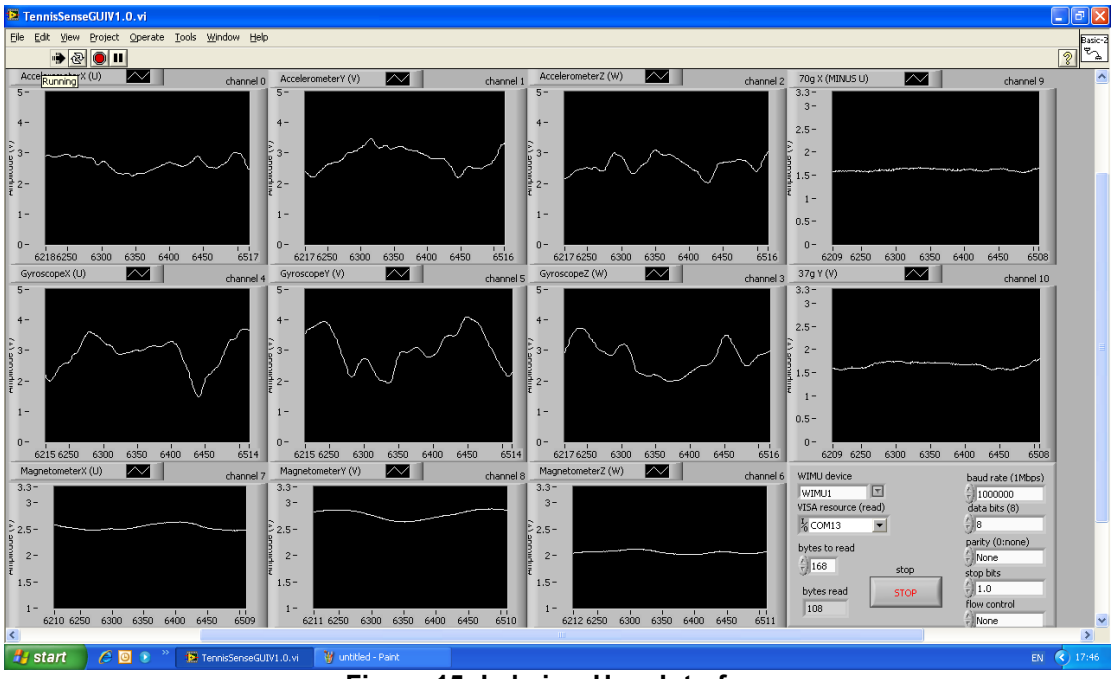



**Figure 15: Labview User Interface**

**Figure 16 GUI controls**

Use “VISA resource (read)” to select the correct COM port for the receiver. Choose the WIMU device using the dropdown menu above this. Serial settings and bytes to read control should be left at default values.

# 5 Important notices

## 5.1 Environmental Operating Conditions

- The receiver should be placed as close to the centre of the tennis court as possible with a direct line of sight between the antennae on the receiver and the WIMUs for best reception.

- If any of the WIMUs are powered off during operation the other WIMUs will continue to transmit data and the base station will continue to receive data from the remaining WIMUs as normal. The WIMU that was turned off can be turned back on at any time and data will be received once again.

- If the receiver is powered off or the USB cable is removed during operation (when the Labview program is running), even momentarily, Labview will no longer be able to continue receiving the WIMU data and the GUI will need to be restarted.

- The correct COM port needs to be chosen in the Labview program to receive WIMU data from the receiver. The specific COM port assigned by the PC for the virtual serial port on the receiver can be checked in the “Device Manager” in Windows. To access the “Device Manager” right click on “My Computer” and select “Properties” or alternatively press the “Windows button” & “Pause-Break” keys to bring up “System Properties“, select the “Hardware” tab and press the “Device Manager” button. Scroll down the list to “Ports (COM &LPT)” and expand it. You should see a list of the assigned COM ports. When you plug in the receiver a new entry should appear here, take a note of the COM port number and use this in the Labview

# 6 References & Datasheets

Gyroscope: ADXRS300 from Analog Devices:
http://www.analog.com/static/imported-files/data_sheets/ADXRS300.pdf

Accelerometer: ADXL210 from Analog Devices:
http://www.analog.com/static/imported-files/data_sheets_obsolete/OBSOLETE%20WATERMARK/ADXL210.pdf

Magnetometer: HMC1052L from Honeywell:
http://www.magneticsensors.com/datasheets/HMC105X.pdf

Radio Transceiver: Nordic nRF2401 Radio from Nordic Semiconductor:
http://www.nordicsemi.com/files/Product/data_sheet/nRF2401rev1_1.pdf

Microcontroller: ATmega128 from Atmel:
http://www.atmel.com/dyn/resources/prod_documents/2467s.pdf

Supplemental Accelerometer: ADXL278 from Analog Devices:
http://www.analog.com/static/imported-files/data_sheets/ADXL278.pdf

Battery: LIP653450UC Rechargeable Lithium Ion Prismatic from Varta:
http://www.varta-microbattery.com/en/mb_data/documents/data_sheets/DS56491.PDF

# 7 Quick Start Guide

Please read these instructions before installing and using the TennisSense system.

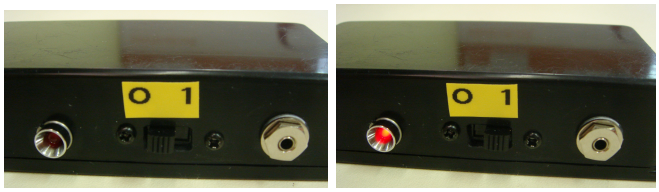
**Contents:**

The TennisSense Demonstrator contains the following items:

- 5 WIMUs (Large)
- 1 WIMU with Velcro-elastic strap (Small)
- 1 Radio Receiver Unit
- 1 Screw-on USB cable
- 3 Battery Chargers
- A copy of the User Manual
- A copy of the internal parts layout drawing
- CD containing drivers, documentation for all devices and Labview code for the attached PC

**Hardware Setup**

Check if all the WIMU units are charged by switching on each of the WIMU devices.




If the LED doesn't light up, the battery may be discharged. Plug the charger into the WIMU only after having checked the polarity before.

**Software Setup**

- Use the files provided on the CD to install the serial over USB driver for the FTDI chip used in the receiver unit.
- If Labview is installed, simply use the Labview VI file provided on the CD
- If Labview is not installed, please install the Labview and Visa runtime provided on the CD

Next, connect the USB cable to the receiver and screw it securely in place, connect the receiver unit to the PC with the USB cable.

Turn on the power switch on the receiver. The green LED should illuminate and the PC should detect the USB receiver as a USB serial device.

**First Use**

- Connect receiver unit to the PC and note the specific COM port that the receiver is assigned to
- Run the Labview program provided and set the COM port used by the Labview program to that used by the receiver
- Put the WIMU units into the wearable pouches/straps and place on the body. Switch the WIMU devices on, ensuring that the power indicator LED is lit (if not the affected unit should be charged using the provided chargers)
- In the Labview program, select the WIMU of interest from the drop down list at the top and ensure it is receiving data. Repeat for other WIMUs.

**Support**

If you have any questions and require support, you can contact us via email on **mark.gaffney (x4023) john.buckley (x4401)**